ARMY RESEARCH LABORATORY

Technical Description and User Notes for LDTRAN/CB Code Used in the Chemical Agent Deposition Analysis for Rotorcraft Surfaces (CADARS) Model

Joseph A. Andrese
Todd R. Quackenbush
Robert M. Mckillip
Thomas B. Curbishley
Milton E. Teske

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Joseph A. Andrese
Survivability/Lethality Analysis Directorate

Todd R. Quackenbush
Robert M. Mckillip
Thomas B. Curbishley
Milton E. Teske
Continuum Dynamics, Inc.

Abstract

The development of a chemical agent challenge-level model for current and future U.S. Army rotorcraft requires both a cloud dispersion model and a sophisticated helicopter aerodynamic effects model. Since the U.S. Army Research Laboratory (ARL) currently possesses chemical-biological (CB) agent cloud generator and dispersion tracking models, this project focused on modeling the rotor wake and airframe interaction with the CB cloud and the deposition of the CB material on the rotorcraft surfaces. The RotorCRAFT/interactional aerodynamics (RC/IA) code was previously developed under the sponsorship of the U.S. Army Small Business Innovative Research (SBIR) program to provide detailed analysis of steady and unsteady airframe loading attributable to helicopter rotor wake-fuselage interactions. The general aim of the effort outlined here was to tailor the RC/IA code to the modeling requirements of rotor-chemical cloud interaction analysis. The work to date has led to the development of the computer code, Lagrangian Deposition and TRajectory ANalysis/Chemical-Biological (LDTRAN/CB), described in this report. The code is the basis of the Chemical Agent Deposition Analysis for Rotorcraft Surfaces (CADARS) model. The CADARS model is a state-of-the-art chemical agent challenge-level predictive system which can be used to efficiently analyze realistic operational scenarios while capturing physically important rotorwash effects. The particular aircraft that has been the focus of work to date has been the U.S. Army RAH-66 Comanche helicopter, although the modeling methods can be extended to analyze any aircraft in the U.S. Army inventory. The biological agent hazards portion of the CADARS model is presently not included in this version.

ACKNOWLEDGMENTS

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In addition, the authors thank Nancy J. Nicholas, Technical Publications Editor, for her excellent editorial assistance.

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PREFACE

The work described in this report was funded under contract DAAL01-95-C-0056 entitled "Rotorwash Modeling for Rotor/Chemical-Biological (CB) Cloud Interaction Analysis." This task is part of a multi-year effort to analyze the survivability of U.S. Army aircraft in environments contaminated by CB agents. Only chemical agents are covered at this stage of the model development. The period of performance for this contract was January 1995 through January 1997.

This document provides the technical background and user instructions for Lagrangian Deposition and TRajectory ANalysis/Chemical-Biological (LDTRAN/CB) modification (Mod) 0.3 code and the accompanying version of the Vortex Trajectory CALCulation program, denoted VTCALC. Previous releases, Mod 0.0 through Mod 0.2, were reviewed and investigated from April through September 1996. The variations were basically similar in function. The differences between the successive revisions were made to improve operation of the LDTRAN interface, to repair errors and inconsistencies identified in initial use, and to optimize the operation of the software for the specific computing environment. Mod 0.3 software constitutes the final release under the activity contemplated in contract DAAL01-95-C-0056. Subsequent releases are projected as a result of ongoing work, which will yield Mod 1.0+ variations of LDTRAN. For all data (including software) first produced by the contractor (Continuum Dynamics, Inc.) under Small Business Innovation Research (SBIR) contract DAAL03-89-C-0004, the contractor provides the same rights as incorporated in Federal Acquisition Regulation (FAR) clause 52.227-20. For all technical data and computer software first produced in the performance of this contract (Army Research Laboratory Contract No. DAAL01-95-C-0056), the contractor provides unlimited rights as addressed in Defense Federal Acquisition Regulation (DFAR) clause 252.227-7013.

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EXECUTIVE SUMMARY

The development of a chemical agent challenge-level model for current and future U.S. Army rotorcraft requires both a cloud dispersion model and a sophisticated helicopter aerodynamic effects model. Since the U.S. Army Research Laboratory (ARL) currently possesses chemical-biological (CB) agent cloud dispersion models suitable for this task, this project focused on addressing the need for a model of rotor wake and airframe effects. The RotorCRAFT/interactional aerodynamics (RC/IA) code was previously developed by Continuum Dynamics, Inc., under the sponsorship of the U.S. Army Small Business Innovative Research (SBIR) program to provide detailed analysis of steady and unsteady airframe loading attributable to helicopter rotor wake-fuselage interactions. The general aim of the effort outlined here was to tailor the RC/IA code to the modeling requirements of rotor-chemical cloud interaction analysis. The work to date has led to the development of the computer code, Lagrangian Deposition and TRajectory ANalysis/Chemical-Biological (LDTRAN/CB), described in this report. A summary of the tasks undertaken in this effort is

- Selective modifications were made in the RC/IA wake model to achieve the optimum balance of physical fidelity and computational efficiency for this application;
- The flow field model was extended to include ground effect computations;
- Appropriate fuselage body modeling methods were implemented;
- Chemical cloud droplet dynamic effects in the presence of rotorwash and ambient turbulence were included;
- A user interface to facilitate operation of the model was developed; and
- A preliminary structure for coupling the rotorwash calculation to the vapor, liquid, and solid tracking (VLSTRACK) cloud model was arranged.

The LDTRAN/CB code developed under this contract is being used as an analysis tool for assessing the effects of chemical agents on the U.S. Army helicopters that may have to fly through chemical clouds to accomplish their missions. This code is the basis for the chemical agent deposition analysis for rotorcraft surfaces (CADARS) model. The biological agent hazards portion of the LDTRAN/CB code will not be used at this time.

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TECHNICAL DESCRIPTION AND USER NOTES FOR LDTRAN/CB CODE USED IN THE CHEMICAL AGENT DEPOSITION ANALYSIS FOR ROTORCRAFT SURFACES (CADARS) MODEL

1. INTRODUCTION

1.1 Objective

The objective of the program has been to combine RotorCRAFT/interactional aerodynamics (RC/IA) with an existing chemical-biological (CB) cloud generator/dispersion model called the vapor, liquid, and solid tracking (VLSTRACK) [1] model, to create a state-of-the-art chemical agent challenge-level predictive system to efficiently analyze realistic operational scenarios while capturing physically important rotorwash effects. The particular aircraft that has been the focus of work to date has been the U.S. Army RAH-66 Comanche helicopter, although the modeling methods can be extended to analyze any aircraft in the U.S. Army inventory.

1.2 Background

The need for accurate helicopter rotor wake modeling has long been known and a wide variety of efforts has been supported in this area by the U.S. Army, the National Aeronautics and Space Administration (NASA), and other Federal agencies. A particularly challenging subset of this general field has been the topic of "interactional aerodynamics" (IA), and several experimental and computational investigations have been undertaken in this area [2,3,4,5]. Broadly speaking, IA is the study of the interaction of the main rotor blade and its wake with the helicopter fuselage, control surfaces, and tail rotor; the applications for this work have been wide ranging, including studies of the effect of wake-airframe interactions on vibrations [6], flying qualities [7,8,9], and performance [10].

Although some useful results were obtained with these models, in the late 1980s, a review of the then-existing capabilities in this area led to an initiative by the U.S. Army Research Office to support development of a new class of wake-airframe interaction software. This led to the development of the RotorCRAFT (RC)/IA code by Continuum Dynamics, Inc. (C.D.I.) [2,3,4,5]. This code was itself a generalization of the earlier RotorCRAFT (Computation of Rotor Aerodynamics in Forward FlighT) software, which was supported by NASA [11]. The thrust of this effort was to apply highly refined free vortex wake modeling techniques to the IA problem (see Figure 1), in combination with newly developed techniques for predicting wake-body interaction.

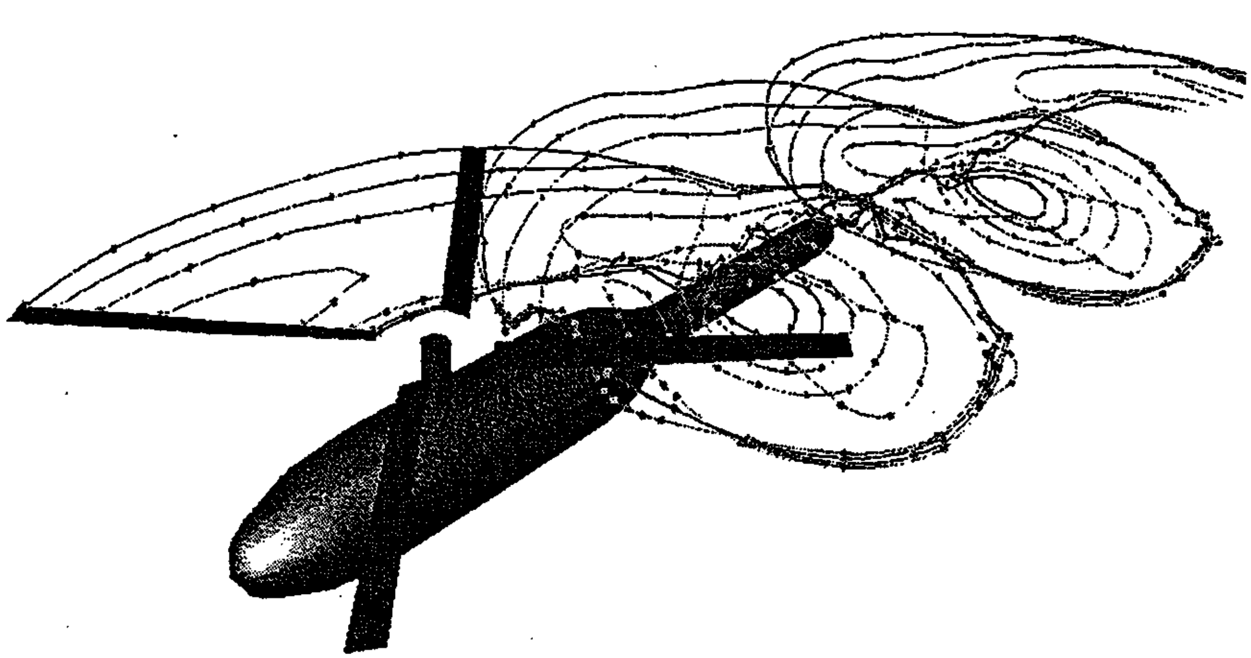
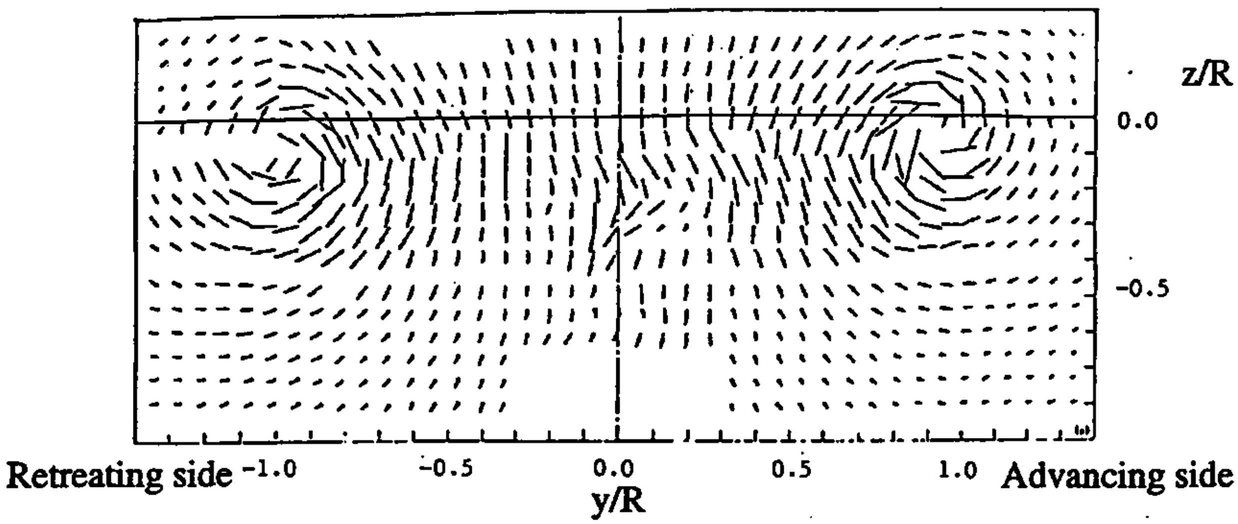
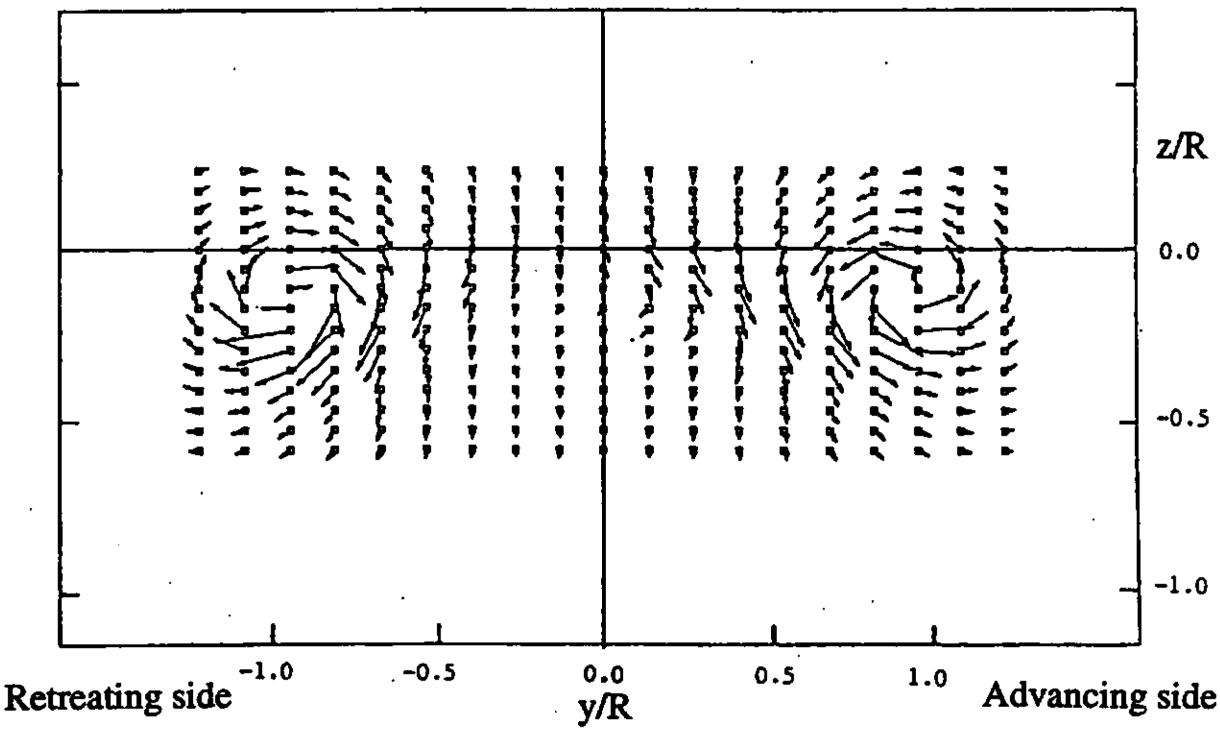


Figure 1. Schematic of the interaction of a constant vorticity contour (CVC) free wake of a rotor with a representative fuselage (only the wake of one blade is shown for clarity).

One focus of the work on the original RC/IA code was to obtain a high resolution modeling capability for the interaction of wake vortices with fuselage surfaces, largely in order to predict vibratory loads. This particular capability is not of interest for the rotorwash-cloud interaction problem, since the time scale of the vortex-surface interaction (VSI) events that drive vibratory loading is much shorter than that required to capture cloud droplet transport onto the surface. However, a prerequisite for accurate VSI is a robust model of the flow field induced by the rotor in the immediate vicinity of the fuselage; accurate definition of the aerodynamic environment associated with wake-body interactions is, for example, central to the prediction of vortex-surface impingement. The existing RC/IA code has very strong capabilities in this area of analysis and thus, the code constitutes a natural starting point for simulating rotorwash interaction with chemical clouds. The original RC/IA model allowed quite general predictions of the rotorwash field for helicopters in steady flight and out-of-ground effect (OGE). References 7 through 11 show several comparisons of predictions made with RC/IA to measured flow field and surface pressure data, including data obtained in U.S. Army and NASA wind tunnel tests. Sample results are shown in Figures 2, 3, and 4, with data from References 12, 13, and 14, respectively. These comparisons are instructive not only because they enhance confidence in the RC/IA model itself, but because the size of the measured rotorwash velocities (20 to 40 ft/sec in forward flight and as much as 70 to 80 ft/sec in low speed flight and hover) makes clear the importance of rotorwash in affecting the transport of fields of small cloud droplets in the vicinity of helicopter fuselages.

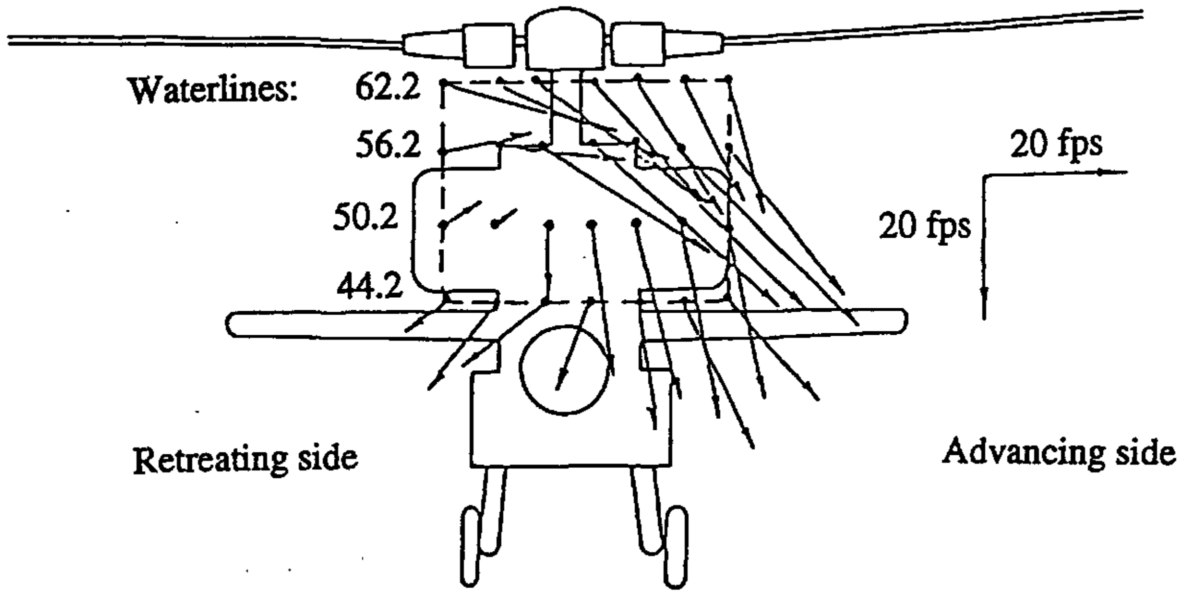


a) Measured velocities

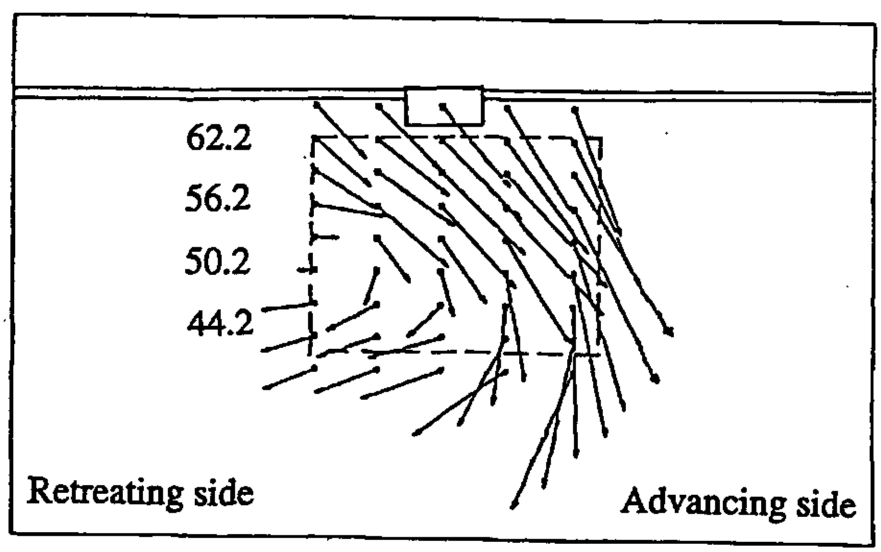


b) Prediction using RC/IA (same scale for velocity vectors as Figure 2a)

Figure 2. Cross flow velocity in a plane 1.07 rotor radii down stream from the hub of a two-bladed rotor at advance ratio 0.14 (view looking forward).

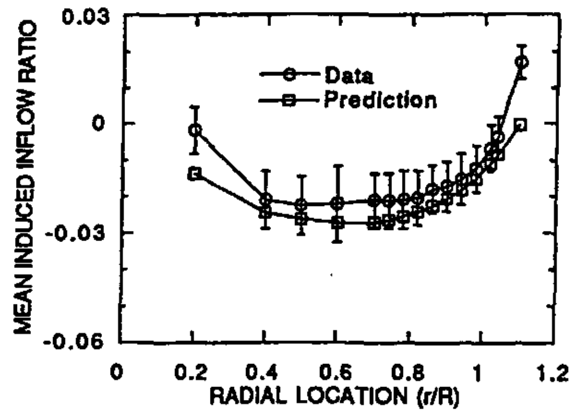


a) Measured velocities [13]

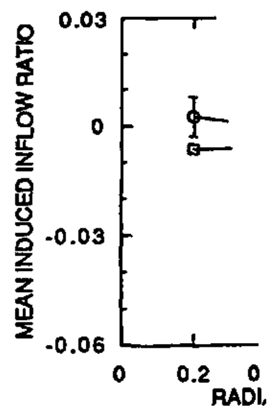


b) Prediction using RC/IA

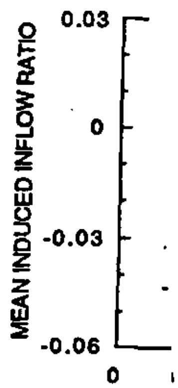
Figure 3. Cross flow velocity in a plane 1.3 rotor radii down stream from the hub of an AH-64 model rotor at advance ratio 0.28 (view looking forward).



a) Azimuth angle $\Psi = 60°$



b) Azimuth angle $\Psi = 180°$



c) Azimuth angle $\Psi = 300°$

Figure 4. Measured and predicted downwash velocities along the radius of the rotor disk for a model rotor-body combination at advance ratio 0.15 **[14]**.

To this point, discussion has focused on rotor wake effects more or less in isolation. At least two other physical modeling effects can play a significant role in defining the flow environment for realistic flight scenarios. The first of these is ground effect, which influences the rotor flow field for aircraft operating at low altitude (rotor hub height less than 1 to 2 rotor diameters); although wake-ground interaction can generally produce very complex flow fields, relatively straightforward modifications of the original RC/IA model (augmenting techniques such as that described in Reference 15) can capture the key effects of ground proximity. The second issue is the role of the fuselage itself, which clearly will substantially affect the flow field in the immediate vicinity of the aircraft. Existing software, including RC/IA, typically uses panel method analyses, which model the surface of the fuselage with a set of distributed singularities (e.g., sources and doublets) whose strength is chosen to ensure flow tangency (i.e., to simulate the no-through-flow condition of solid bodies). Such methods offer a very flexible and general way to represent the flow field around the fuselage and can yield, given appropriately detailed input about fuselage geometry, a similarly high level of detail about the local flow field.

This high resolution, however, can have a high computational cost, and it is clearly necessary to apply the most efficient methods available. Such methods are available in the form of fast hierarchical panel methods developed as part of recent work at C.D.I. [16,17], and these methods have been applied as part of the present effort.

To adequately address the rotor-chemical cloud interaction problem, it is also clearly necessary to properly characterize the ambient concentration of chemical material. Techniques for modeling the evolution and dispersion of chemical clouds have been studied for many years. Simplified line source models of the dispersal of such airborne material were developed in the 1970s [18], although cloud transport and diffusion models have evolved substantially since that time, making available such tools as the VLSTRACK model [1]. Codes such as VLSTRACK are well suited to the problem of capturing the large scale diffusion and transport of chemical cloud material. However, for small scale problems such as those of interest here, it is appropriate to augment them to incorporate local transport effects attributable to droplet mass and aerodynamic drag. Modeling of such phenomena has been done here, drawing upon development work for the Forest Service Cramer-Barry Grim (FSCBG) code, a general PC-based analysis of the dispersion of aerially released material. This particular code originated in the mid-1970s and has undergone extensive revision and development at C.D.I. since 1989 [19,20,21,22], including incorporation of an advanced near-field droplet transport model embodied in the Agricultural Dispersal (AGDISP) code.

As indicated by this brief review, at the outset of this effort pre-existing simulation tools contained much of the raw capability needed to address rotor wash-chemical cloud evolution computations, but a coupled model with the appropriate balance of fidelity and efficiency did not exist. The following sections outline the technical substance of the methods used to synthesize such a model, drawing upon appropriate elements of the RC/IA, AGDISP and FSCBG codes, as well as more recent work on aircraft icing [23].

2. METHODOLOGY

2.1 Technical Approach and Assumptions

2.1.1 *Technical Approach*

The overall technical approach proposed for this effort was to adapt and optimize the existing RC/IA model to compute the rotor-body flow field, while incorporating additional features drawn from FSCBG, AGDISP, and other relevant software to track the trajectory and dispersion of chemical material near the aircraft. The fundamental objective of the effort was to accurately compute the wake- and body-induced velocity field around the helicopter to predict the deposition of chemical agent material at or near critical points on the aircraft fuselage. The discussion in this section focuses on particular technical challenges addressed and also presents an outline of the operational concept envisioned for use of the initial use of this software. In addressing these topics, it is important to note several key assumptions made during the development of the initial version of Lagrangian Deposition and TRajectory ANalysis/Chemical-Biological (LDTRAN/CB) code.

2.1.2 *Assumptions*

2.1.2.1 The model presently represents only one aircraft, the RAH-66 Comanche, and rotor wash effects are calculated for that specific rotor system.

2.1.2.2 The mission profile of the aircraft to be simulated with LDTRAN/CB consists of one or more "legs" involving operation at hover, constant forward speed, and altitude. Thus, though an arbitrary number of such legs at different heights and speeds (from hover to high speed cruise) can be studied; conditions such as maneuvering flight are not addressed.

2.1.2.3 It is assumed that the aircraft encounters clouds of chemical material whose lateral dimensions are large compared to the rotor diameter and whose dimension along the flight path is such that for the duration of a particular leg, the aircraft may be assumed to encounter a spatially homogeneous cloud of uniform concentration. Each leg is assigned a set of cloud properties, so that fluctuations in cloud structure may be imposed by choosing the duration of each leg to match the flight time through particular cloud structures.

2.1.2.4 A high resolution description of the body surface geometry is used, but the fluid dynamic model that computes its influence neglects the effect of viscosity. Given this, the effect of flow separation from various aircraft components (e.g., the rotor hub) will not be captured.

2.1.2.5 For in-ground effect calculations, the ground surface is represented by a flat plane at a specified height below the aircraft, neglecting local terrain contours or other obstructions.

2.1.2.6 The model presently computes only the deposition of airborne chemical material on the fuselage and does not capture the effect of evaporation or "stripping" of material from the surface.

2.2 Modeling and Analytical Techniques

The following discussion elaborates the implementation of the model under the specified assumptions, although any of the assumptions just noted could be relaxed through additional development. For example, Assumption 5 regarding material deposition will be bypassed in a future release of LDTRAN/CB projected for mid-1997.

2.2.1 *Rotorwash Modeling*

The first class of issues addressed in the development of LDTRAN/CB involved basic features of the modeling of the rotor wake. The full span continuous vorticity contour (CVC) wake model (see Figure 1) used in the baseline RC/IA code was developed for use in very high resolution studies of unsteady blade-wake interaction but also has demonstrated very strong capabilities in predicting wake-induced flow fields in the presence of realistic fuselages (as discussed in References 2 through 4, excerpts from which are shown in Figures 2 and 3). However, owing largely to the level of detail embedded in the full span model, the original RC/IA code was very computationally intensive. Substantial reductions in the number of vortex elements used in the wake model were effected without adversely impacting the level of accuracy required for predicting the time-averaged velocity fields used for transporting chemical cloud material.

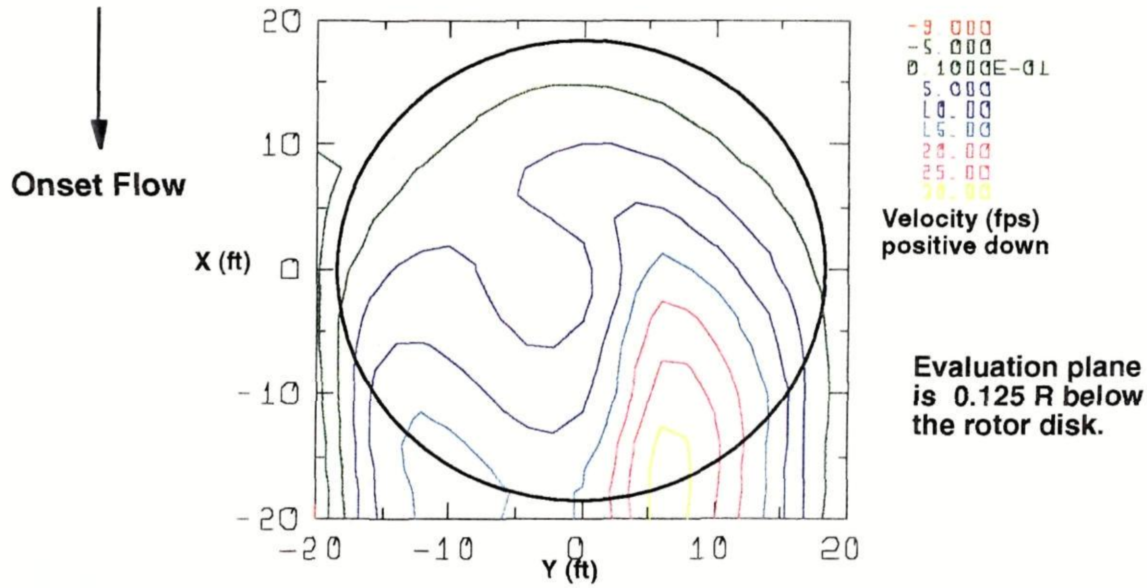
The appropriate level of modeling for current purposes was assessed through extensive test calculations of predicted flow fields at key points near the rotor, with the goal of achieving time-averaged velocities essentially identical to those produced by the full span model with a greatly reduced computational burden. The best balance of accuracy and efficiency was achieved with a wake model consisting of two free vortex filaments trailing from each blade, one from the blade tip and one in board from the 40% radial station; this model is identical to that used successfully in References **24** and **25** to model rotor blade motion in low speed flight. Figure 5 shows a typical comparison of time-averaged downwash velocities computed using both this model and the full span free wake model; the velocities in this case were calculated in a plane 0.125 rotor diameter (2.5 ft) below the plane of the rotor of a RAH-66 Comanche in forward flight at 90 knots and are given in terms of contours of constant downwash (in feet per second, with velocity positive down). While nearly identical in their predictions, these two models differed by a factor of more than 10 in the computation time required.

The new wake model was embodied in a focused set of routines whose primary task is computing the geometry of the vortex wake of the rotor and its resultant velocity field. This software was designated the Vortex Trajectory CALCulation (or VTCALC) program and is used as a preprocessor for the LDTRAN/CB code. (Appendix A describes the operation of the VTCALC code module, and Appendix B details the procedures for inserting rotorwash flow fields generated by VTCALC into the LDTRAN/CB library structure.).

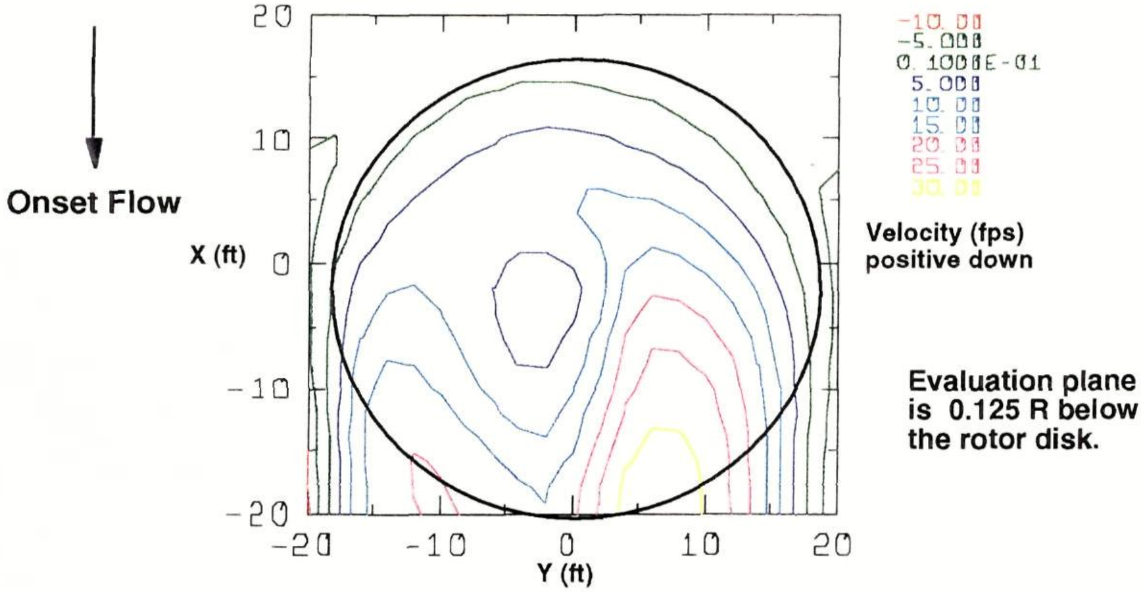
Given the close agreement shown by the VTCALC model with the predictions of the validated parent full span free wake analysis in RC/IA, its physical fidelity in terms of rotorwash velocity predictions is judged to be very good. However, direct correlation studies of the deposition of material on helicopter fuselages (an element of planned future activity) will, of course, be the most appropriate test.

2.2.2 *Fuselage Body Modeling*

The velocity field of the wake itself is only a part of the complete flow field induced by the rotor-body combination. The gross effects of the presence of the fuselage clearly must be incorporated. In the original RC/IA code, this was done using well-known panel method techniques similar to those used in several industry-standard software packages **[26]**. These methods operate by locating panels composed of distributed source flows on the surface of the fuselage. The surfaces of the panels are designed based on flow tangency to the body surface, thus simulating the actual solid fuselage surface. Although the effects of viscosity (and thus of skin friction and flow separation) are neglected, these source-based panel methods have a favorable history of successful correlation of surface pressures for rotorcraft fuselages, as shown in References **2** through **5**.



a) Prediction with the VTCALC free wake model



b) Prediction with the full-span CVC free wake model from RC/IA

Figure 5. Comparison of downwash velocity predictions for the RAH-66 Comanche isolated main rotor using the VTCALC and RC/IA wake models (the flight condition is 90 knots at a thrust coefficient of 0.007 [gross weight 10,000 lb] [R = radius = 19.5 ft]).

In the absence of separation, the effect of flow gradients inside the fuselage boundary layer on the initial deposition of chemical material will be small for the Reynolds' number range of interest here; the subsequent transport of the material under the strong shear experienced in this region, however, may be important and will be one subject of an ensuing investigation. The effect of large scale separation may be still more significant, especially in the case of computations of the deposition in the lee of large outstanding structures such as the rotor mast. Although the present model cannot capture the recirculating flow that often characterizes such regions, it should produce acceptable tolerance predictions of deposition. Direct modeling of separation effects is still a topic of basic research in computational fluid dynamics; some elements of current models could be applied to advantage in the problem of interest here but would require at least an order of magnitude increase in the computational effort involved.

Panel methods are attractive, partly because they are capable of modeling a wide variety of bodies, from fixed wing aircraft to ground vehicles and enclosures. For this effort, attention was focused on a single rotorcraft, the U.S. Army RAH-66 Comanche. To obtain an adequate panelization of the Comanche fuselage, a Ballistics Research Laboratory computer-aided device (BRL-CAD) **[27]** description of the aircraft geometry was downloaded, and C.D.I. proprietary software was used to extract the surface coordinates and construct a series of surface panelizations. There is considerable latitude in the number of panels that can be used in representing the fuselage, and a series of studies was made of the trade-offs of computational cost and accuracy of the predicted flow fields using various numbers of panels. For this effort, the original source panel model was augmented by the accelerated fast hierarchical panel methods described in References **16** and **17**.

Figure 6 shows the final configuration used in this effort for the Comanche, which uses 1200 surface panels. This particular panelization uses a relatively even distribution of panels over the surface, though this distribution can be customized to focus on particular locations, if desired. This panel representation provides not only a body-induced flow field that modifies the trajectories of droplets but also produces surface pressure distributions that can be used in other applications, such as studies of chemical material infiltration.

2.2.3 *Ground Effects Modeling*

Another significant technical element required for modeling realistic flight profiles is ground effect. Operation of helicopters in nap of the earth (NOE) flight typically involves proximity to the ground, with hub heights in some cases comparable to or less than the rotor diameter. It is well known that hub heights of one to two rotor diameters or less can significantly affect rotor-body aerodynamics and the flow field around the fuselage. Previous C.D.I. rotor software has incorporated ground plane effects for rotors in hover and forward flight **[15, 17]**. The approach used in LDTRAN/CB is to distribute source panels on the ground plane to impose flow tangency, thus simulating a solid boundary and effecting the wake deflection and (in hover) recirculation characteristic of rotors' in ground effect. Figure 7 shows a typical snapshot of the tip vortex trajectory of a Comanche rotor-fuselage combination in hover in ground effect, showing the strong distortion in the filament trajectory that occurs at a hub height of one rotor radius.

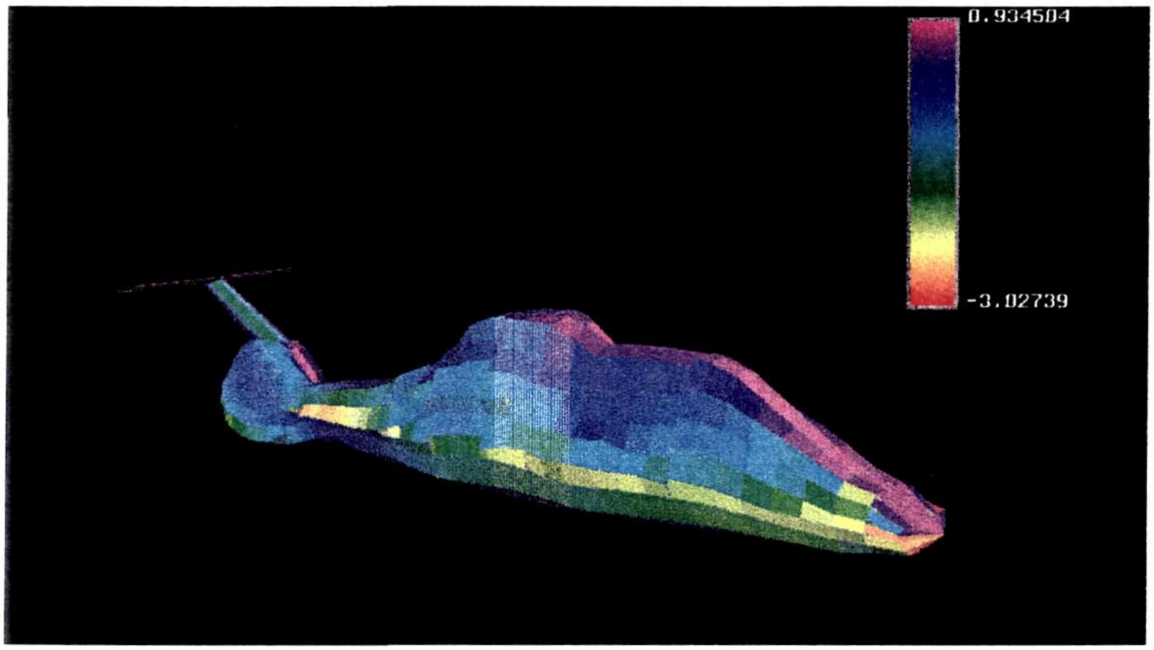


Figure 6. Pressure coefficient distribution over the Comanche fuselage in high speed forward flight.

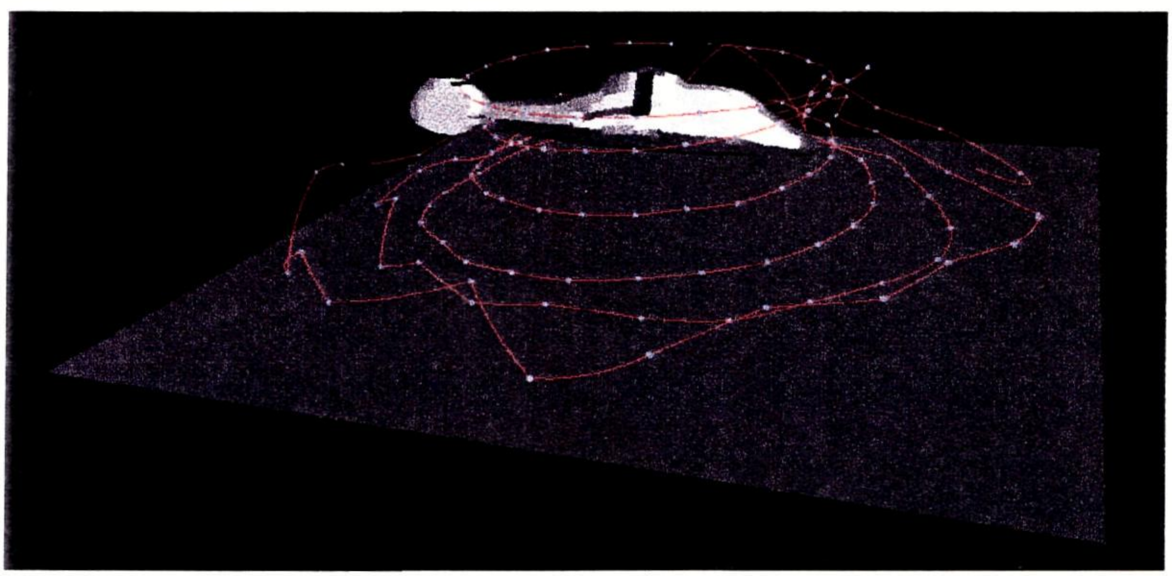


Figure 7. Tip vortex geometry for a Comanche rotor in hover in ground effect: rotor hub height = one blade radius.

2.2.4 *Droplet Transport, Dispersion, and Deposition Modeling*

The coupled effect of the body, the rotor and its wake, and (when appropriate) the ground are computed on a volumetric grid of points around the aircraft, and a time-averaged flow field is computed. (Time averaging is invoked since the flow field around a rotor is periodic with a period of roughly 0.05 second; fluctuations on this time scale were judged to be sufficiently short to be averaged for the purposes of droplet transport.) This flow field is then used to convect an array of droplets from starting positions on the boundary of the computational grid until they either impact on the fuselage surface or encounter another boundary of the grid. Using efficient interpolation and numerical integration schemes adapted from the FSCBG/AGDISP code, droplet trajectories are generated for each of the user-selected mission segments and chemical agents. The distances between the droplet trajectories and the panel centroids are then used in an interpolation scheme to compute the effective collection rate (mass/time) on each panel surface for each flight condition. Total accumulation on a panel is computed by scaling this collection rate by the total duration of exposure to a particular ambient concentration of the chemical agent in question.

The particular set of equations that govern the motion of the droplets are as follow:

$$\frac{d^2X_i}{dt^2} = (U_i - V_i)\left[\frac{1}{\tau_p}\right] + g_i \tag{1}$$

$$\frac{dX_i}{dt} = V_i \tag{2}$$

in which the relaxation time τ_p is

$$\tau_p = \frac{4}{3}\frac{D\rho}{C_D\rho_a|U_i - V_i|} \tag{3}$$

Here, the position of the ith droplet is expressed as a mean X_i and turbulence-induced perturbation as x_i. The corresponding droplet mean and fluctuating velocities are V_i and v_i, respectively, while U_i represents the mean ambient flow speed at location i. Finally, D represents the droplet diameter, C_D the droplet drag coefficient, ρ the density of the droplet, and ρ_a the density of air. Droplet drag coefficient is computed as a function of Reynold's number, which in turn is a function of droplet diameter and kinematic viscosity. Kinematic viscosity is interpolated from a table of standard atmosphere properties for a given temperature, and both the droplet diameter and ambient temperature are input directly from the LDTRAN/CB interface. Selection of the agent determines the specific gravity of the droplet, which is converted to a droplet density in the calculation of the droplet time constant.

Evolution equations for the fluctuating components themselves are also tracked using

$$\frac{d}{dt}\langle x_i x_i \rangle = 2\langle x_i v_i \rangle \tag{4}$$

$$\frac{d}{dt}\langle x_i v_i \rangle = \left[\langle x_i u_i \rangle - \langle x_i v_i \rangle\right]\frac{1}{\tau_p} + \langle v_i v_i \rangle \tag{5}$$

$$\frac{d}{dt}\langle u_i v_i \rangle = 2\left[\langle u_i v_i \rangle - \langle v_i v_i \rangle\right]\frac{1}{\tau_p} \tag{6}$$

in which the bracket notation denotes the ensemble average of the fluctuating quantities. The original derivation for this development of the mean equations for the particle trajectories and their variance (or "spread") $\langle x_i x_i \rangle$ is given in Reference **20**. The model has been well validated through more than 10 years of application in the AGDISP code. The software for this portion of the computation is embodied in a routine denoted Simulation Program for Liquid and Aerosol Trajectories (SPLAT).

Figure 8 shows a typical set of mean trajectories for particles released upstream from a Comanche fuselage in forward flight. The combined effect of the body and the rotor wash is evident in the figure. To compute the mass rate of deposition of cloud material on the surface, each panel interrogates the population of particle trajectories in its vicinity and extrapolates the particle velocities to the panel centroid. Using the (user-specified) volumetric density of droplets ρ_{mpd} (expressed in droplets/unit volume) in the assumed cloud, the rate of mass accumulation at panel k is determined by

$$\frac{dm_k}{dt} = -A_k(\vec{n}_k \cdot \vec{q}_k)\rho_{mpd} \tag{8}$$

in which A is the panel area, $\vec{n}$ is the outward normal vector to the panel at the panel centroid, and $\vec{q}$ is the extrapolated velocity at the panel. This computation of deposition on the surface of the aircraft is performed in the Summation Procedure for Representing Externally Accreted Droplets (SPREAD) module of LDTRAN/CB. Figures 9 and 10 show typical results for depositing material on a Comanche in two forward flight cases using the complete LDTRAN/CB model, indicating the different "hot spots" of high deposition computed for each case.

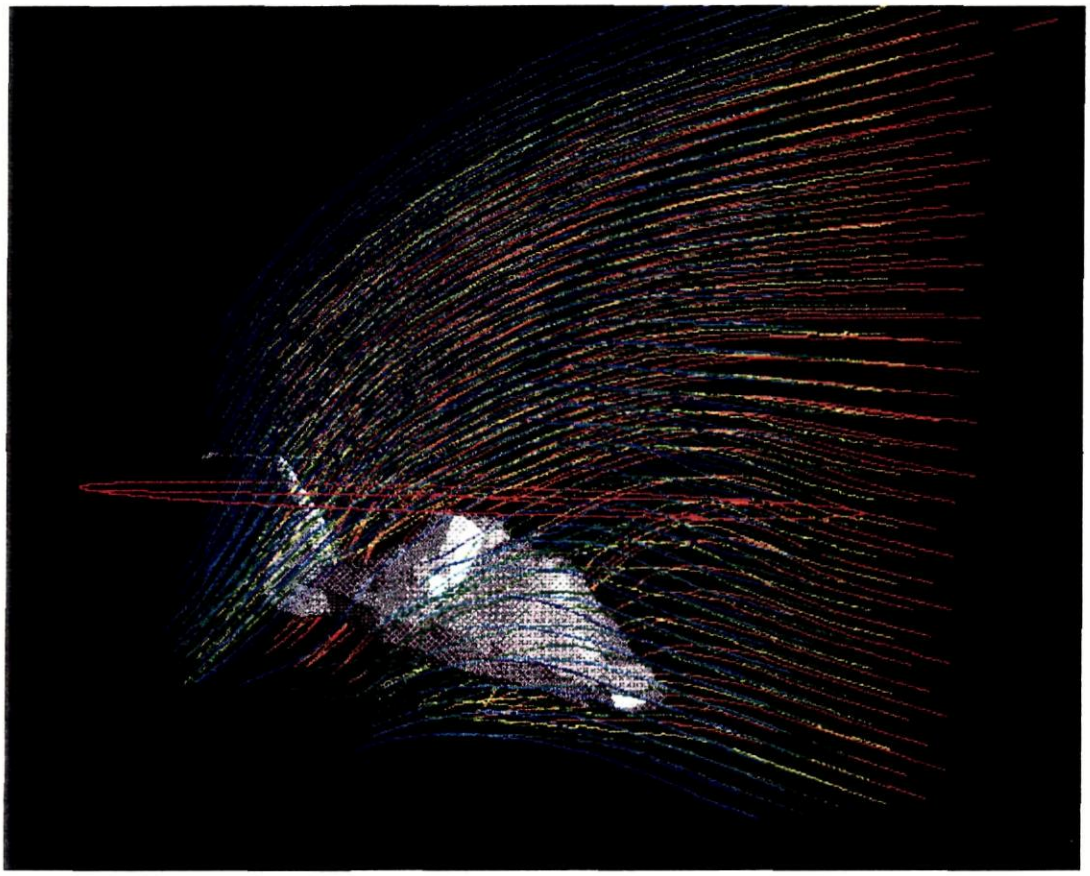


Figure 8. Typical cloud droplet particle trajectories predicted by LDTRAN/CB at 40 knots forward speed.

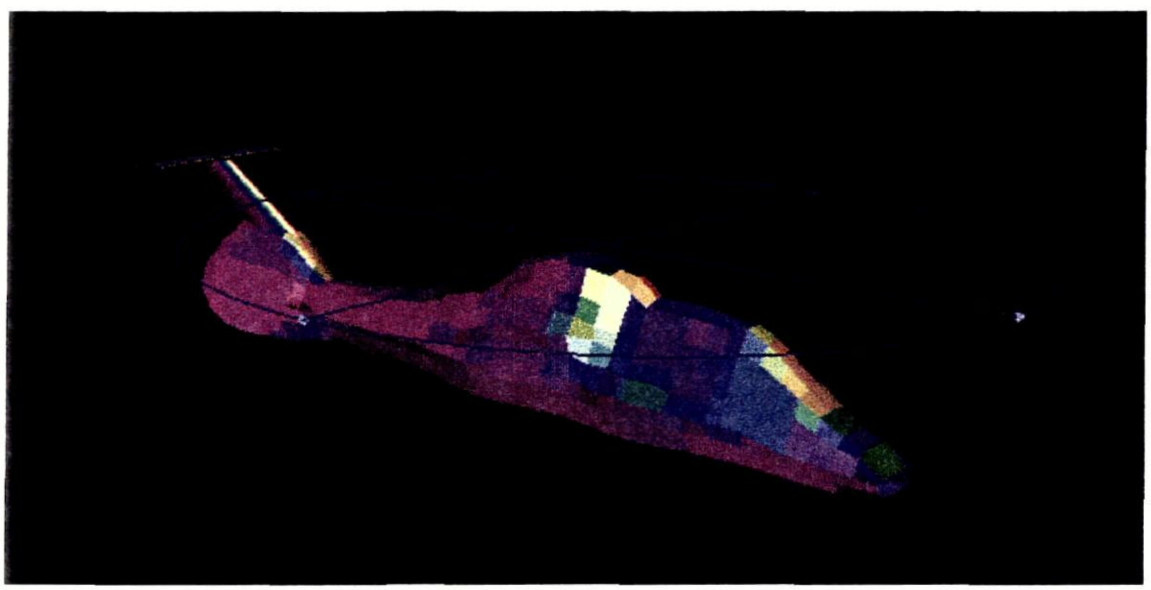


Figure 9. Plot of deposition rate (relative) over the Comanche fuselage surface, including rotor wash: flight at 80 knots, out of ground effect (red=high deposition, indigo=low deposition).

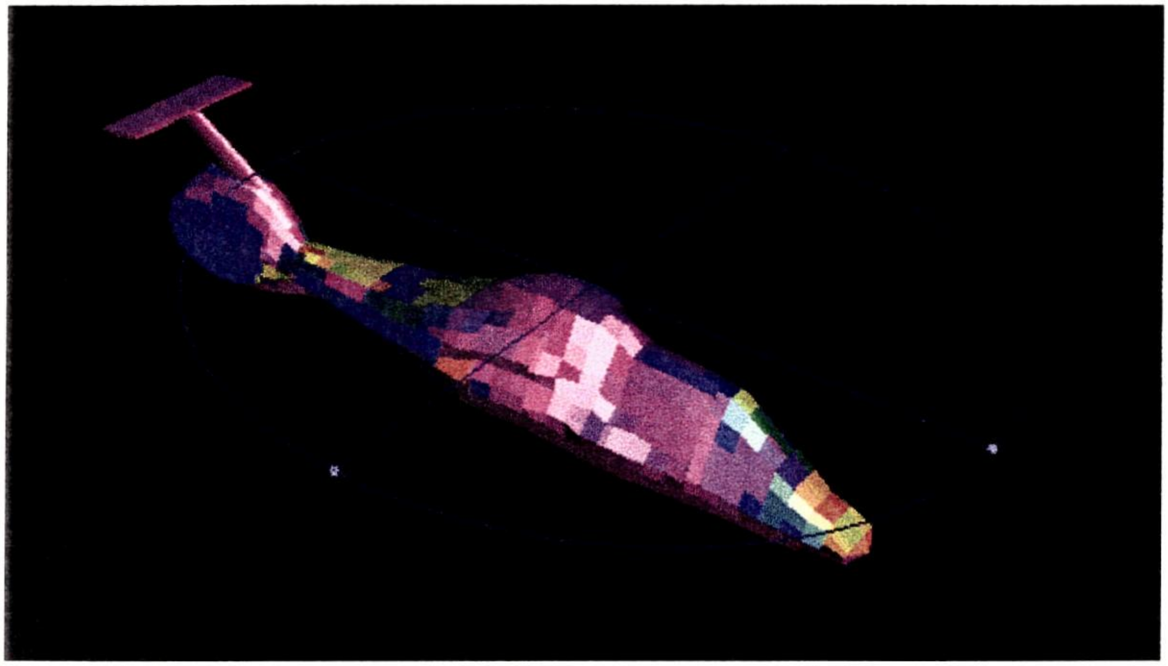


Figure 10. Plot of deposition rate (relative) over the Comanche fuselage surface, including rotor wash: hover, out of ground effect (red=high deposition, indigo=low deposition).

2.2.5 *User Interface Techniques*

Another technical task addressed during this effort was the construction of a graphic user interface suitable for mediating between the user and the LDTRAN/CB model. The operational details of this interface program are the subject of much of the remaining discussion, so only a brief outline of its structure is given here. The present user interface is built on X-windows and the Motif widget set. A single window holds all the input controls, which take the form of pull-down menus, text boxes, and option buttons. The number of controls has been kept to a minimum for the sake of simplicity. The interface has been designed so that an operator can construct a mission scenario by selecting a vehicle from a list and then build a mission profile. The profile consists of a group of "legs" defined by a name, a flight condition, a duration or distance, specified meteorological parameters and a chemical agent encountered. Both the flight condition (drawn from the ARL-specified matrix of speed/height operating states) and the chemical agent are selected from a list, shielding the operator from the complexities of the parameters they represent. The lists become indices into extendible "libraries" of available run data; more data can be added to these libraries, increasing the number of options available to the operator. Once the scenario is defined, the operator begins the simulation with the click of a button. When the run is complete, the user interface also makes available tools for examining predicted results, both graphically and numerically.

2.2.6 *Coupling with VLSTRACK*

The final technical task addressed as part of this effort was to set up a preliminary coupling of LDTRAN/CB with the VLSTRACK model. The VLSTRACK model provides a potentially rich source of information about cloud concentration and structure for notional operational scenarios. While VLSTRACK is tailored to conduct large scale, long time simulations of chemical cloud evolution, information from it would very useful in setting the incident cloud density used in the LDTRAN/CB model. The present level of coupling allows information about chemical agents and ambient conditions to be read from VLSTRACK to LDTRAN/CB. It also allows the user to download data about cloud concentration from VLSTRACK.

2.3 Code Structure

The flow chart shown in Figure 11 shows the overall structure of the present version of LDTRAN/CB. Specification of the helicopter rotor geometry and the aircraft flight condition (i.e., airspeed, altitude, gross weight) along with the fuselage geometry data permits initialization of the rotor wash-body computation of velocity fields in VTCALC. This generates time-averaged velocities on a grid of points surrounding the rotor and the aircraft; this velocity field is used to transport chemical cloud droplets through the domain around the vehicle, as described in Appendix A. Transport is accomplished through activation of the SPLAT code module using time integration of particle trajectories from initial particle locations on the boundaries of the computational domain around the aircraft.

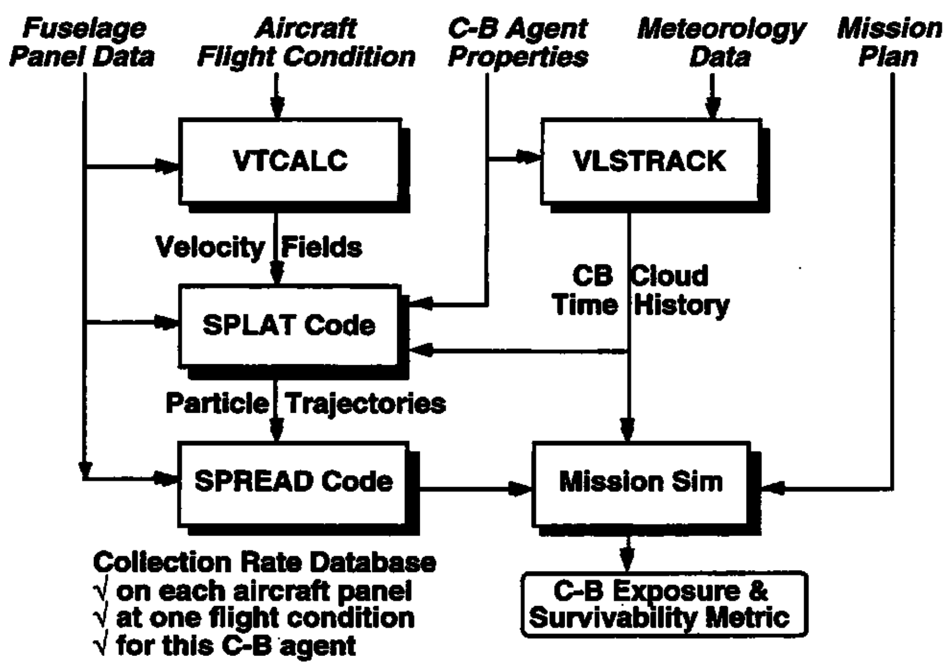


Figure 11. Flow chart of the Mod 0.3 version of the LDTRAN/CB code.

In the current Mod 0.3 version of LDTRAN/CB, both the initial positions have been determined by "off line" pre-calculation and are fixed for each flight condition. User-determined inputs to this module include the fuselage body geometry, flight condition, ambient conditions, and chemical agent properties (droplet density, concentration, droplet size distribution); this information can also be obtained from VLSTRACK input files, if desired. With these inputs, numerical integration of particle trajectories continues until the droplets terminate on the aircraft surface or reach the boundaries of the grid around the aircraft. These computed trajectories are the principal output of the SPLAT module.

The particle trajectories produced by SPLAT are then used to determine local mass deposition rates at each panel on the surface of the aircraft using the SPREAD module. In essence, the role of the coupled VTCALC, SPLAT, and SPREAD modules of the LDTRAN/CB analysis is to generate a database of deposition rates at individual panels as a function of flight condition and cloud droplet characteristics. Given this and knowledge of the cloud properties from VLSTRACK and other sources, deposition histories for very general mission scenarios can be produced. The following section outlines the user interface that has been designed to facilitate the construction of input for such mission simulations using LDTRAN/CB as well as to display the key computational results.

2.4 LDTRAN/CB User Interface Input and Output

This section provides guidance about the present version LDTRAN/CB user interface. As of the current Mod 0.3 release, the interface should be considered beyond the beta testing stage, although additional modifications and improvements are expected during the development of the Mod 1.0+ versions that are projected for 1997. The present interface is written in the C programming language and is built on X-Windows and the Motif widget set. The interface itself and the major subprograms should be compatible with Silicon Graphics Incorporated (SGI) Irix versions 5.3 and above.

Instructions for installing the program and setting up the default directory structure and preferences are included in separate installation notes delivered with the software. These initial steps should be taken before attempting to invoke LDTRAN/CB. The installation instructions presume that the program-executable files and library files will be stored in a set of subdirectories below a "main" directory (simply denoted "ldtran" for this discussion). Once installed, the program is invoked by issuing the command "ldtran" either within the ldtran/bin directory or from some other directory via an appropriate shell script or symbolic link.

Once activated, a main interface window will appear; the functions of the interface broadly are to facilitate data definition (input), execute calculations, and inspect output. The following discussion addresses the input requested for each of the major areas of this window and the associated pop-up windows, as well as the existing pull-down menus. Features present but not currently active are also briefly described to convey the capabilities that are anticipated for ensuing versions of LDTRAN/CB.

2.4.1 *Input Data Definitions*

Pull-Down Menus

Four pull-down menus are provided in this area: **File, Run, Edit**, and **Help.**

File

Open	Selecting this item opens a window with a file browser to allow input sets to be read to initialize a calculation. Selecting an LDTRAN/CB input file within this window (or typing a file name in the Selection window) and clicking OK causes the input data to be read into the program for subsequent editing or execution. Once this occurs, the name of the file should appear in the window labeled **LDTRAN Data File** (.ldt file extension).
Save	Saves the open LDTRAN/CB data set in the **LDTRAN Data File** window (.ldt file extension).
Save as...	Saves the open LDTRAN/CB data set under a user-selected name, which will appear in the **LDTRAN Data File** window.
Exit	This exits the LDTRAN/CB interface.

Edit

Cut	Removes a selected text string from temporary storage.
Copy	Copies a selected text string from temporary storage.
Paste	Returns a selected text string to temporary storage.
Clear	Deletes selected string.

(NOTE: The four **Edit** functions are not active in Mod 0.3.)

Options...	Selecting this item opens a window that allows default preferences and program options to be chosen, determining the directory path to the library files, chemical agent files, and program support (i.e., location of executable files). See installation notes for further details about initial setup. Select OK to confirm choice.

Run Runs LDTRAN/CB code. Same as lower Run click button.

Help Invokes on-line help (not active in Mod 0.3).

Dialog Boxes

VLSTRACK Interface

This option is not active in Mod 0.3. A preliminary method for downloading data about ambient atmospheric conditions and chemical cloud properties directly from VLSTRACK output files has been formulated and coded but has not been activated in LDTRAN/CB pending ARL user requirements. The projected functioning is as follows: checking the box Use VLSTRACK Data will open a file browser that will select a set of VLSTRACK data files to be attached to the input to the code run. This will determine the agent to be used in the run as well as the ambient meteorology (note that this will disable subsequent user inputs for these categories). The mission trajectory defined in the input boxes described next will also be interfaced with VLSTRACK output to determine the concentration of chemical material encountered by the vehicle.

Vehicle

In this area, the user selects the type of vehicle of interest for the calculation. In the initial release of LDTRAN/CB, the only active option in the initial Mod 0.3 release is the RAH-66 Comanche helicopter. However, additional entries will be activated in subsequent releases. This selection causes a vehicle geometry file with the appropriate name to be found and accessed in the library/directory.

Chemical Agents

Here, the user may select from among a catalog of chemical agents for use in the simulation. The available agents are those listed in Table 1. At present, LDTRAN/CB accesses the VLSTRACK output file VLSTRACK.AGN to read the specific gravity of individual agents. Droplet diameter must be specified.

Meteorology

This box allows the user to specify ambient meteorological conditions. At present, the only active parameter required for input is **temperature**. This parameter determines the kinematic viscosity of air in the desired operating condition, which contributes to the determination of aerodynamic drag on cloud droplets.

Table 1. Agents Accessible to LDTRAN/CB from the VLSTRACK Database

VX	Thickened HD
GA (Tabun)	AC (HCN)
GB (Sarin)	CK (CNCl)
GD (Soman)	CG (Phosgene)
GF	Toxic Org. 1
HD (Mustard)	Toxic Org. 2
L (Lewisite)	Toxic Org. 3
HN-3	SF6 (sim.)
HL (mixture)	Dusty VX
CX (solid)	Dusty GA
DMMP (sim.)	Dusty GB
DMHP (sim.)	Dusty GD
BIS (sim.)	Dusty GF
TCP (sim.)	Dusty HD
MS (sim.)	Bio Agent 1a
DMA (sim.)	Bio Agent 1b
DEM (sim.)	Bio Agent 2a
TEP (sim.)	Bio Agent 2b
Water (sim.)	Bio Agent 3a
Thickened VX	Bio Agent 3b
Thickened GA	Bio Agent 4
Thickened GB	Bio Agent 5
Thickened GD	Glass Beads
Thickened GF	

Mission Profile

Start Point: Here, the user may specify the starting latitude and longitude. This information is not used in Mod 0.3, but the input has been put in place to prepare for subsequent versions that will interact with VLSTRACK, whose specification of ambient conditions can be tied to latitude/longitude coordinates.

The box below **Start Point** is a display of the assumed set of flight conditions for the projected mission, which is described in terms of a discrete set of legs. Each leg is described within this display box by the following fields of data:

Leg Name: User-specified designation for this leg.

Flight Condition: Speed and altitude of the aircraft during this leg. (Note: Altitude is typically characterized as out-of-ground effect (OGE), in-ground effect (IGE), or high IGE (HIGE). In Mod 0.0, IGE denotes a hub altitude of 25 ft, while HIGE denotes an altitude of 50 ft; OGE encompasses all altitudes above 50 ft. These results will be generalized in subsequent releases that concern other aircraft. Table 2 shows the flight conditions built in to the LDTRAN/CB (Mod 0.3) library.

Table 2. RAH-66 Flight Conditions in the LDTRAN/CB (Mod 0.3) Library

Effects (Altitude) and Flight Modes	Speed
Out-of-Ground Effect (> 50 ft.):	
Hover	Hover
Nap of the Earth	15 knots
Nap of the Earth	40 knots
Contour	85 knots
Contour	100 knots
Low Level	120 knots
Low Level	150 knots
Low Level	180 knots
In-Ground Effect (25 ft):	
Hover	Hover
Nap of the Earth	15 knots
High In-Ground Effect (50 ft):	
Hover	Hover
Nap of the-Earth	15 knots
Nap of the Earth	40 knots

End Point: The data fields in this area contain the type of information to be specified about each leg (bearing/distance or bearing/time) and two numerical fields in which (in the case of bearing/distance input) the bearing in degrees of the leg and its spatial length (in kilometers) are entered; if bearing/time is selected, the second numerical field contains the duration of the leg in minutes. The duration is the actual quantity used by LDTRAN/CB to compute total deposition on the fuselage; in the case of bearing/distance input, the duration of the leg is internally computed from the user inputs of distance and forward speed.

Concentration: For each leg of the mission profile, the user may enter the ambient concentration of the chemical agent selected. The units are g/m^3.

Modifications of the legs may be made by using the **Add** or **Edit** buttons just below the **Mission Leg** display box. Selecting an existing line and clicking **Add** will introduce a new leg above (previous to) the selected one. Selecting an existing line and clicking **Edit** will allow this leg description to be altered. Clicking **Remove** will delete an existing leg.

Invoking **Add** or **Edit** (or double-clicking on a line) will activate the **Mission Leg Editor** pop-up, which allows the entries described above to be entered or modified. The available data entry windows are

Leg: Enter here a name for this leg.

Leg Specification: Specify either bearing/distance or bearing/time. (Recall that for a leg involving hover, bearing/time should be selected.)

Bearing: Orientation of the flight path in degrees relative to north (not active in Mod 0.3, so an entry of 0.0 is appropriate).

Distance (in kilometers) or **time** (in minutes): Enter the appropriate quantity for the leg consistent with the previous choice of **Leg Specification**.

Flight Condition: Click this to select from among the available rotorwash velocity files in the library/subdirectory.

Concentration: Enter the ambient chemical concentration in parameter (either particle number or mass) per cubic meter.

The **OK** button selects the set of inputs in the active fields, while **Cancel** returns to the main window. **Help** is not active in the Mod 0.3 release. Once selected, the entered data should appear in the main window. At this point, the computation is ready to run. Note that at least one leg must be entered to initiate the calculation, while the number of legs is effectively unlimited.

2.4.2 *Computation*

With the mission profile specification completed, the user may activate the **Run** button, which will initiate the calculation. Once the calculation is running, a pop-up window will appear, giving the status of the job. The window contains a specification of the code module which is currently active as well as the leg being analyzed. Clicking the **Abort** button stops the existing job and returns to the main window.

2.4.3 *View Results*

The current release of LDTRAN/CB supports the generation of five major data sets as a consequence of its operation. Output data sets for each of these five categories are generated for each leg of the mission profile selected. These can be accessed by clicking **View Results,** which activates the **View Calculation Results** window. The first step is to click the **Select Results for Viewing** button. For each leg, six categories of output can be viewed, along with the input used on the body geometry. Activation of the first visual options described next invokes

LDPLOT, which is functionally equivalent to the CDI SGPLOT software forwarded to ARL in January 1995. The images presented may be manipulated in a manner consistent with the instructions previously supplied. The American Standard Code for Information Interchange (ASCII) output text may be viewed through the interface or accessed with more conventional file-handling techniques.

The major outputs are

1) **Body Geometry**: This option displays the fuselage panelization employed for this run in monochrome gray.

2) **Flow Velocity Vectors**: This displays arrows denoting the local velocity field vectors. The vector magnitudes indicate flow speed.

3) **Particle Paths**: This will display a set of trajectories of cloud droplet particles for the selected leg. Colorization is chosen here by the particle index.

4) **Panel Pressure**: This presents the surface pressure p in terms of its pressure relative to the ambient level, defined as ($p-p_{ambient}$) in kiloPascals. Thus, red indicates high pressure, while blue indicates low pressure.

5) **Panel Mass Collection Rate** (per area): Here, red indicates a high mass deposition rate, while blue indicates a low value. The color scale is set by the values on a given leg, so plots are not directly comparable on different legs. The units are in g/m^2-sec.

6) **Panel Cumulative Mass** (per area): Red indicates a high cumulative mass deposition, while blue indicates a low value. Again here, the color scale is set by the values on a given leg, so plots are not directly comparable on different legs. The units are in g/m^2.

Additional visual interface output is available by using the center mouse button to click on a panel surface in several of these displays. First, use the right mouse to show the screen menu and select "Show Nodes." Clicking on a node with the center button will yield a printout of the panel number, the physical quantity, and the location of the panel center in shaft coordinates. This function is available in the panel pressure, mass collection rate, and cumulative mass windows.

Along with the available visual output, the user may access an ASCII file associated with the last three panel displays. For the collection rate data, these are panel number, normal particle velocity (m/s), panel area (m^2), volumetric collection rate (m^3/sec), and the three body-axis velocity components (m/sec). For the panel pressures these are panel number and differential pressure (in kiloPascals). Finally, for the cumulative mass data these are panel number, mass per area (gm/m^2), panel area (m^2), and total accumulated mass (grams).

2.4.4 *Run Re-Initialization*

Currently, once a run is completed and the results are inspected, a new run may be executed by modifying the input and re-starting the calculation. Changing the name in the **LDTRAN Data File** window before rerunning will ensure that old results are saved and can be re-examined at a later time. Rerunning with the same data file name will overwrite old results.

3. CONCLUSION AND RECOMMENDATION

The information in this report summarized the background, development, and functioning of the Mod 0.3 release of the LDTRAN/CB code. As noted previously, the focus in this initial stage of development has been on assembling a model suitable for predicting chemical agent deposition on rotorcraft operating in a wide range of flight conditions and also capable of interacting with standard chemical cloud simulations such as VLSTRACK. The present version invokes a variety of simplified assumptions that are suitable for use in this initial demonstration version but should be relaxed to address the full range of problems of interest in studying rotorwash-chemical cloud interaction problems. These limitations include neglect of evaporation and stripping chemical material off the fuselage surface and the lack of provision for "pickup" or displacement of previously deposited material. Additional development to address these issues is recommended and was initiated in January 1997 as part of ensuing work, which will be directed at extending the correlation data base for LDTRAN/CB and at simulating additional rotorcraft in the Army inventory.

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APPENDIX A

USER NOTES ABOUT THE VTCALC ROTORWASH PREDICTION MODULE

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USER NOTES ABOUT THE VTCALC ROTOR WASH PREDICTION MODULE

1. GENERAL INFORMATION

1.1 Summary

Vortex Trajectory CALCulation (VTCALC), MOD 0.0, is a FORTRAN computer program that can be used to determine the velocity field induced by a lifting rotor in the presence of fuselage bodies, a ground plane, or both. VTCALC (MOD 0.0) uses a free wake constructed from basic curved vortex elements (see Reference 2) and a lifting surface representation constructed of panels (see Reference 3) to calculate the induced motion of the vortices. In its present form, VTCALC constitutes a simplified version of the C.D.I. RotorCRAFT/AA (Mod 1.0) code (see Reference 4), which in turn has integrated portions of the interactional aerodynamics capabilities inherent in the earlier RotorCRAFT/IA code (see Reference 4). VTCALC is specifically designed to provide flow field and surface pressure input for the LDTRAN (Lagrangian Deposition and TRajectory ANalysis) program. This version of VTCALC (MOD 0.0) was developed specifically for the RAH-66 Comanche; future versions will address more general single-rotor helicopters, although the releases of VTCALC projected for 1997 will be directly integrated with LDTRAN/CB and will prompt the user for input via the LDTRAN/CB X-Windows interface.

1.2 Environment

VTCALC (MOD 0.0) is written in FORTRAN 77 and is being operated on Silicon Graphics Inc. (SGI) Iris and Indigo computers) at Continuum Dynamics, Inc. These systems use the SGI Irix 5.3 operating system.

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2. OPERATION

2.1 Initiation

In order to initiate processing, the user must assign the following files:

UNIT	TYPE	I/O	DESCRIPTION
3	ASCII	I	Run Characteristics Input File
body.bin	BINARY	I	Binary Surface Panel Input File

The initiation of VTCALC (MOD 0.0) for a given flight condition produces time-averaged flow field output at desired grid point locations in space, as well as average pressure values for each panel surface defined in input file "body.bin." The file "body.bin" is a user-selected panelization of the aircraft fuselage. The flow induced by this panelized representation in the presence of the rotor wake is a component of the final time-averaged flow field.

At Continuum Dynamics, Inc. (C.D.I.), initiation is performed by running the command file @vt [Name 1]. This command file executes VTCALC as a batch job. VTCALC (MOD 0.0) is provided in subdirectory "SARL/script" on the software distribution tape.

[Name 1], the run name, identifies the Run Characteristics Input File: [Name 1].inp. All output is placed in subdirectory [Name 1]dir.

The "@vt" script currently runs under C.D.I.'s Irix 5.3 operating system, although some SGI systems may not accept the script commands. An alternate way to execute VTCALC (MOD 0.0) without the "@vt" file is to create a subdirectory designated [Name 1], copy the necessary files into that subdirectory, and initiate the job in the subdirectory by typing "vtcalc." This variation is found in subdirectory "SARL/noscript," which contains files for a version of VTCALC that directly incorporates the file-handling operations contained in the "@vt" script in the source code.

Initiation of VTCALC as a stand-alone program is discussed further in Appendix B.

2.2 Inputs

This section shows the format of the VTCALC Run Characteristics Input File. $$$ denotes a comment line. Comment lines are placed between each input line in the Run Characteristics Input File in order to quickly identify the parameters when editing.

When VTCALC is initiated with the script file "@vt," the input file should be present (on the same directory level as the script file) as [Name 1].inp.

When VTCALC is initiated without the script file, the input file should be present as "fort.3" in a subdirectory called [Name 1]dir. The VTCALC executable should also be in this subdirectory. A binary surface panel input file named "body.bin" must be present in the same directory as the Run Characteristics Input File. Formats for the input files are shown on the

When VTCALC is initiated with the script file "@vt," the input file should be present (on the same directory level as the script file) as [Name 1].inp.

When VTCALC is initiated without the script file, the input file should be present as "fort.3" in a subdirectory called [Name 1]dir. The VTCALC executable should also be in this subdirectory. A binary surface panel input file named "body.bin" must be present in the same directory as the Run Characteristics Input File. Formats for the input files are shown on the following page; sample files are delivered with the VTCALC software and are further described in Section 3.

RUN CHARACTERISTICS INPUT FILE:

$$$[Comment line giving a description of the run, repeated at the head of the Run Results Output File]
$$$
NBLD,RAD,OMEGA
$$$
GW
$$$
MU,RHO,IGE,ALT

VARIABLE	TYPE	MEANING
NBLD	INT	Number of rotor blades.
RAD	REAL	Rotor radius (m).
OMEGA	REAL	Tip speed (rad/sec).
GW	REAL	Gross weight (kg).
MU	REAL	Advance ratio (forward speed/OMEGA*RAD).
RHO	REAL	Air density (kg/m^3).
IGE	INT	Ground effect flag: set IGE=1 if in ground effect.
ALT	REAL	Altitude above ground plane (m): always enter a value (if IGE=0, this value is not used).

Note: For this version (MOD 0.3), use only NBLD=5, and RAD and OMEGA for the RAH-66 Comanche single-rotor helicopter. ALL DIMENSIONAL VALUES ARE ENTERED IN METRIC UNITS.

BINARY SURFACE PANEL INPUT FILE:

```
NPNL
FOR IP=1,NPNL
 IPNLT(IP)
 (PNLCNR(I,L,IP),I=1,3,L=1,INPLT(IP))
NEXT IP
```

VARIABLE	TYPE	MEANING
NPNL	INT	Number of panels.
IPNLT(IP)	INT	Number of sides of panel IP, (Currently 3 or 4).
PNLCNR(I,L,IP)	INT	I=1,2,3 correspond to the X,Y,Z shaft coordinates (Z positive down along the rotor shaft, X positive forward, Y positive to the right) defined moving in a counter-clockwise direction around the panel. The right-hand rule identifies the side of the panel facing the flow field.

Note: Two binary surface panel input files are provided with this version of VTCALC (MOD 0.0): "body.bin," a low-density RAH-66 Comanche fuselage (with tail) composed of 1099 panels, and rah66_hires.bin, a more densely defined Comanche fuselage (with tail) composed of 7340 panels.

The binary surface panel input file used by VTCALC must always be designated "body.bin." The "body.bin" file provided with the sample files is the low-density RAH-66 fuselage file (1099 panels).

2.3 Outputs

Output files are assigned to the following unit numbers and are found in subdirectory [Name 1]dir:

DESCRIPTION	NAME	UNIT
the Run Results Print File	[Name 1].prt	20
the Pressure Output File	[Name 1].cp	25
the Time-averaged Velocity Scan Grid Output File	[Name 1].vel	38

The Run Results Print File is an ASCII file which summarizes the run characteristics and provides standard output for each calculation step so the user can estimate how quickly and/or successfully the calculation is proceeding. The Pressure Output File and the Time-averaged

Velocity Scan Grid Output File are binary files generated for use in the LDTRAN program. Note that pressure is generated in units of kiloPascals (kPa).

2.4 Reference Frame

All fuselage panel position coordinates, wake-induced velocities, and cloud particle positions are expressed in the rotor shaft coordinate frame. This reference frame has its origin at the center of the main rotor hub, with the Z coordinate pointing down along the rotor shaft, the X coordinate pointing forward perpendicular to the shaft in the plane of symmetry of the fuselage, and Y pointing right, perpendicular to Z and X via the right-hand rule. However, the aircraft is always assumed to be in steady, level flight, so the forward speed of the aircraft is always assumed to be directed parallel to the ground plane.

3. SAMPLE FILES

VTCALC program software is provided in two subdirectories: "SARL/script" for the software to be initiated with the "@vt" script file, and "SARL/noscript" for the software to be used without a script file. Each subdirectory also contains a "makefile" which will compile the program and generate the executable, "vtcalc."

Two sets of sample files are provided with the VTCALC software. Each set of files represents a flight condition of 180 knots (advance ratio = 0.42), out-of-ground effect, with the low density body panelization.

Sample files for initiating a run <u>with a script file</u>:

The Run Characteristics Input File is designated "sample.inp," and the Body Surface Panel Input File is designated "body.bin." VTCALC is initialized by typing

@vt sample

Directory "sampledir" will be generated by VTCALC and will contain output files "sample.cp," "sample.vel," and "sample.prt."

Sample files for initiating a run <u>without a script file</u>:

Input files necessary to execute VTCALC are in subdirectory "sample2dir." The Run Characteristics Input File is designated "fort.3," and the Body Surface Panel Input File is designated "body.bin." When the program is initiated this way, the executable "vtcalc" must also be in this subdirectory. CAUTION: the executable should be compiled from the "SARL/noscript" subdirectory. After the executable is copied into subdirectory "sample2dir," VTCALC is initialized by typing

vtcalc

from that subdirectory. Six output files will be produced in the subdirectory: fort.14, fort.17, fort.21, cp, vel and prt. Of these, only "cp," "vel," and "prt" are of interest. The "fort" files can be deleted after the program has executed.

The default Body Surface Panel Input File, "body.bin," represents the low-density panelization containing 1099 panels. The high density panelization containing 7340 panels is also provided and is designated "rah-66_hires.bin".

APPENDIX B

INSTRUCTIONS FOR INSERTING VTCALC RESULTS IN LDTRAN

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INSTRUCTIONS FOR INSERTING VTCALC RESULTS IN LDTRAN/CB

The following instructions provide a "cookbook" procedure for producing a new entry in LDTRAN's library of flight conditions. The VTCALC code generates velocity field and pressure data, and some housekeeping tasks are required to locate new data files in their proper places in the library directory structure.

Note that in the following sample problem some of the directories are listed by their complete path name. The first part of these path names will vary from installation to installation, so you will need to make adjustments for your particular system. The following paths will be referenced to a notional file hierarchy with top level /u1 with /arl immediately below. It is assumed that the LDTRAN/CB file structure will be built from this point, first creating a subdirectory ldtran (/u1/arl/ldtran), and appending the library structure from the tape containing LDTRAN/CB.

Sample problem:

Add a new flight condition to LDTRAN's library that represents a Comanche flying at 60 knots, 50 feet above the surface of the earth.

Step 1 - Gather input data for VTCALC:

For VTCALC, all values are input in metric units. We will need the following data to define our problem (VTCALC input values in boldface):

Forward speed:	60 knots x 0.514 = 30.84 m/sec
Advance Ratio:	101.3 ft/sec / (37.16 rad/sec x 19.5 ft) = 0.14
Number of rotor blades:	5
Rotor radius:	19.5 feet = 5.95 m.
Rotor angular speed:	354.85 RPM x 2p rad / 60 sec/min = 37.16 rad/sec
In ground effect?	yes (set the IGE flag to 1)
If yes, height of the rotor hub:	50 feet = 15.2 m.
Gross vehicle weight:	10162 lbs = 4609 kg
Air density:	.002378 slugs/ft^3 (SL std. atm.) = 1.226 kg/m^3

Step 2 - Create a Run Characteristics File for VTCALC:

Using a text editor, create a Run Characteristics File for the flight condition, as described in Appendix A.

If you are initiating the run with a script file:

By convention, the Run Characteristics File will be named "14i.inp" (the advance ratio times 100, with an "i" appended to it indicating that ground effect is enabled). This file must be placed in a "vtcalc" directory, created by the user. Bold type indicates commands entered by the user.

```
% cd /ul/arl/vtcalc
% vi 14i.inp
```

If you are initiating the run without a script file:

The Run Characteristics File will be named "fort.3" and must be placed in a subdirectory of "vtcalc." It is recommended that this subdirectory be named according to the same convention cited above (i.e., "14idir"). Bold type indicates commands entered by the user.

```
% cd /ul/arl/vtcalc/14idir
% vi fort.3
```

Run Characteristics File ("14i.inp" or "fort.3") contents:

```
Sample run - 60 knots at 50 feet
NBLD    RAD    OMEGA
  5     5.95   37.16
GW
4609.0
MU    RHO     IGE   ALT
0.14  1.226    1    15.2
```

Step 3 - Copy the Body Panel File:

VTCALC requires a Body Surface Panel Input File, named "body.bin," that describes the geometry of the vehicle body. We can obtain this body panel file from the LDTRAN library directory. If you are initiating the run with a script file:

Copy the appropriate body.bin file to the "vtcalc" directory.

```
% cd /ul/arl/vtcalc
% cp /ul/arl/ldtran/library/vehicles/RAH-66_Comanche/body.bin .
```

For the Comanche, the default file is the lower density body panelization containing 1099 panels, located in "library/vehicles/RAH-66_Comanche/body.bin," as shown above. If the higher density panelization containing 7340 panels is desired, it is located in "library/vehicles/RAH-66_hires/body.bin":

```
% cp /ul/arl/ldtran/library/vehicles/RAH-66_hires/body.bin.
```

If you are initiating the run <u>without a script file</u>:

Copy the appropriate body.bin file to the "vtcalc/14idir" directory.

```
% cd /u1/arl/vtcalc/14idir
% cp /u1/arl/ldtran/library/vehicles/RAH-66_Comanche/body.bin.
```

For the Comanche, the default file is the lower density body panelization containing 1099 panels, located in "library/vehicles/RAH-66_Comanche/body.bin," as shown above. If the higher density panelization containing 7340 panels is desired, it is located in "library/vehicles/RAH-66_hires/body.bin":

```
% cp /u1/arl/ldtran/library/vehicles/RAH-66_hires/body.bin.
```

<u>Step 4</u> - Run the VTCALC code (see Appendix A):

If you are initiating the run <u>with a script file</u>:

VTCALC runs take a long time to complete. A shell script called "@vt" takes care of the task of defining directories and submitting the calculation job to the computer's batch queue. "@vt" takes one argument, the run name, which for this example is "14i." Note that the run name is the same as that of the Run Characteristics File without the ".inp" extension.

```
% cd /u1/arl/vtcalc
% @vt 14i
```

If you are initiating the run <u>without a script file</u>:

The VTCALC executable must be copied into the "14idir" subdirectory of "vtcalc":

```
% cp /u1/arl/vtcalc/SARL/noscript/vtcalc /u1/arl/vtcalc/14idir/.
```

The program can now be initiated from the "14idir" subdirectory:

```
% cd /u1/arl/vtcalc/14idir
% vtcalc
```

VTCALC runs take a long time to complete, so it is recommended that they be run in batch.

<u>Step 5</u> - Copy the VTCALC output files to the LDTRAN library directory:

If you initiated the run <u>with a script file</u>:

Upon successful completion VTCALC produces a directory that contains three data files. The directory's name is built from the run name chosen in Step 4, with "dir" appended to it. For this example, the directory would be named "14idir." Inside the directory are three files: the print file (14i.prt), the pressure file (14i.cp), and the velocity field file (14i.vel). Of these files, only the last two are used by LDTRAN. Copy them into the LDTRAN library directory as follows:

```
% cd /u1/arl/vtcalc/14idir
% cp 14i.cp /u1/arl/ldtran/library/vehicles/RAH-66_Comanche/cps
% cp 14i.vel /u1/arl/ldtran/library/vehicles/RAH-66_Comanche/vels
```

If you initiated the run without a script file:

Upon successful completion VTCALC produced six files in the directory from which it was launched. For this example, that directory would be "14idir." Three of the files produced are "fort" files "fort.14," "fort.17," and "fort.21"; these can be ignored. Three other files are produced: the print file (prt), the pressure file (cp), and the velocity field file (vel). Of these files, only the last two are used by LDTRAN. Copy them into the LDTRAN library directory as follows:

```
% cd /u1/arl/vtcalc/14idir
% cp cp /u1/arl/ldtran/library/vehicles/RAH-66_Comanche/cps
% cp vel /u1/arl/ldtran/library/vehicles/RAH-66_Comanche/vels
```

Step 6 - Copy the appropriate Initial Condition file into the library:

In order to generate valid particle trajectories, a set of initial conditions must be defined for the particles. Three template files are provided with LDTRAN. Select the proper file by examining the advance ratio for the problem.

File	Advance Ratio
hover.ics	A.R. = 0.0
transition.ics	0.0 < A.R. <= 0.06
forwardflight.ics	A.R. > 0.06

For this example the proper initial condition file is "forwardflight.ics." Copy this template to a file that has the run name defined in Step 4 and the extension ".ics."

```
% cd /u1/arl/ldtran/library/vehicles/RAH-66_Comanche/icees
% cp forwardflight.ics 14i.ics
```

Step 7 - Edit the Index file for the vehicle:

Each vehicle in the library has an index that associates a descriptive name and a flight speed with each flight condition. For the Comanche, this index is

/u1/arl/ldtran/library/vehicles/RAH-66_Comanche/index

Each line in this file describes a single flight condition and contains the run name, the flight speed (in knots), and a short descriptive title. The order of the entries in the file determines the order of the flight conditions displayed in LDTRAN. Insert a new entry for the new flight condition in this file and save the file. For this example, the new entry might be

14i 60 60 kts 50 ft IGE

This completes the addition of a new flight condition into the LDTRAN library. The next time LDTRAN is launched, this flight condition will be available in LDTRAN's controls.

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